Comment on "Dispersion Velocity of Galactic Dark Matter Particles"

N.W. Evans

Theoretical Physics, Department of Physics, 1 Keble Rd, Oxford, OX1 3NP, United Kingdom

(February 1, 2008)

PACS numbers: 95.35.+d, 98.35.Ce, 98.35.Gi, 98.62.Gq

The recent Letter of Cowsik, Ratnam and Bhattacharjee [1] claims that the best fit value of the velocity dispersion of the Galactic dark matter is $\sim 600\,\mathrm{km\,s^{-1}}$. If correct, this is a significant result that should lead researchers to design new experiments to detect very high energy weakly interacting massive particles. The interpretation of the Galactic microlensing data for massive compact halo objects [2] would require substantial, far-reaching revision.

The basis of the analysis of Cowsik *et al.* is an iterative scheme that solves the coupled Poisson and collisionless Boltzmann system of equations (Eqs. (3) and (4) of their Letter). There is no reason whatsoever to believe that the velocity distribution of the collisionless dark matter is Maxwellian. Rather, the distribution of velocities that supports the dark matter halo against gravitational collapse must be found by solving the self-gravitation equations. Almost all known dark matter halo models do not have simple Maxwellian velocity distributions [3]. Dark matter halos with Maxwellians have a number of simple properties. The iso-density contours of the dark matter must coincide with the global equipotentials. For a flattened self-gravitating system, the contours of constant density are always flatter than the equipotentials [4]. Only for spherical self-gravitating halos can the iso-density and equipotential surfaces exactly coincide. In the inner parts of the model described by Cowsik *et al.*, the halo feels the gravity of the disk and the spheroid and so is flattened. In the outer parts, the gravitational potential of the halo overwhelms that of the exponentially declining disk and the comparatively puny spheroid. As the halo feels only its own gravity field, the dark matter density distribution becomes round. The assumption of a Maxwellian velocity distribution now must inexorably drive the halo model to the spherical solution of the Poisson and collisionless Boltzmann equations with a Maxwellian. This always has the asymptotic behaviour of the isothermal sphere [5].

So, Cowsik *et al.*'s numerical algorithm should yield a dark matter halo that deviates from the isothermal sphere only in the inner parts of the Galaxy. If the dark matter three-dimensional velocity dispersion is $\langle v^2 \rangle_{\rm DM}^{1/2}$, the halo must become indistinguishable at large radii from the isothermal sphere with rotation curve of amplitude $\sqrt{\frac{2}{3}} \langle v^2 \rangle_{\rm DM}^{1/2}$. Evidently, then, Fig. 1. of Cowsik *et al.*'s original Letter [1] cannot be the whole story. For example,

the model with $\langle v^2 \rangle_{\rm DM}^{1/2} \sim 600\,{\rm km\,s^{-1}}$ must match asymptotically onto an isothermal sphere with a rotation curve of amplitude $\sim 490\,{\rm km\,s^{-1}}$. But, Fig. 1 shows the rotation curve of this model is $\sim 200\,{\rm km\,s^{-1}}$ and apparently still slowly falling at a Galactocentric radius of $\sim 20\,$kpc. This can only be reconciled with our line of reasoning if the rotation curve rises very steeply at larger Galactocentric radii. That this indeed happens is confirmed by the astonishing rotation curve provided in Fig. 1 of Cowsik *et al.*'s response [6] to this comment. This does have the right asymptotic behaviour – and betrays the physical origin of Cowsik *et al.*'s high dark matter velocity dispersion! The model has an extensive envelope of dark matter at Galactocentric radii $\sim$ 1Mpc. This is untenable, as it is in clear and unambiguous contradiction with the mass estimates of the Local Group provided by, for example, the timing argument [7]. To estimate the mass in Cowsik *et al.*'s model, let us roughly approximate the rotation curve of Fig. 1 of [6] as two piecewise continuous segments, one of amplitude $\sim 250\,{\rm km\,s^{-1}}$ out to $\sim 50\,$kpc, the second of amplitude $\sim 550\,{\rm km\,s^{-1}}$ from $\sim 50\,$kpc to 1 Mpc. This provides an estimate of the mass within 1 Mpc as

$$M \sim \int_0^{1\,{\rm Mpc}} \frac{v_0^2 dr}{G} \sim \frac{1}{4.31 \times 10^{-6}} \Big[250^2 \times 50 + 550^2 \times (10^3 - 50) \Big] \sim 6.7 \times 10^{13}\,{\rm M}_\odot \qquad (1)$$

Peebles [7] reckons the mass within the Local Group as $\sim 4.3 \times 10^{12}\,{\rm M}_\odot$, so Cowsik *et al.* violate this constraint by over an order of magnitude! It is the pressure required to balance the weight of the overlying layers of this phenomenal mass at large radii that causes the high dark matter velocity dispersion. Cowsik *et al.* argue that their result is robust for all pressure-supported haloes as the moment $\langle v^2 \rangle_{\rm DM}^{1/2}$ appears as the pressure term in the Jeans equations. This is untrue. The Jeans equations tell us that $\langle v^2 \rangle_{\rm DM}$ behaves roughly like the gravitational potential ψ. The deeper a potential well, the higher the velocity dispersion required to support the model. To achieve their anomalously high velocity dispersion, Cowsik *et al.* have simply taken a much deeper central potential than is reasonable or warranted!

REFERENCES

[1] R. Cowsik, C. Ratnam and P. Bhattacharjee, Phys. Rev. Lett. **76**, 3886 (1996).

[2] C. Alcock *et al.* , Phys. Rev. Lett. **74**, 2867 (1995); E. Aubourg *et al.* , Astron. Astrophys. **301**, 1.

[3] N.W. Evans, Mon. Not. R. Astron. Soc. **260**, 191 (1993); N.W. Evans, Mon. Not. R. Astr. Soc. **267**, 333 (1994).

[4] J.J. Binney and S.D. Tremaine, *Galactic Dynamics* (Princeton University Press, Princeton, 1987), chaps. 2,4.

[5] D. Lynden-Bell, R. Wood, Mon. Not. R. Astron. Soc. **138**, 495 (1968)

[6] R. Cowsik, L. Ratnam and P. Bhattacharjee, Phy. Rev. Lett., submitted (astro/ph 9608035)

[7] P.J.E. Peebles, in *Gravitational Dynamics*, eds. O. Lahav, E. Terlevich & R.J. Terlevich, Cambridge University Press, p. 219 (1996)